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NACA

RESEARCH MEMORANDUM

FLUTTER INVESTIGATION IN THE TRANSONIC RANGE OF SIX AIRFOILS ATTACHED TO THREE FREELY FALLING BODIES

By

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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FLUTTER INVESTIGATION IN THE TRANSONIC RANGE OF SIX AIRFOILS ATTACHED TO THREE FREELY FALLING BODIES

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SUMMARY

Results of tests of six flutter wings, two swept 45° and four unswept, attached to three freely falling bodies are reported. Two unswept wings fluttered at transonic Mach numbers of 0.840 and 0.895, and two similar wings with 45° sweepback fluttered at 0.920 and 0.925. Flutter frequency and phasing were recorded. One unswept wing reached the top Mach number of the bomb, $M = 1.145$, without flutter or failure. The telemeter channel of the sixth wing was inoperative.

Two-dimensional, incompressible flutter theory for unswept wings was used to calculate reference flutter velocities of these wings for preliminary comparison with other experimental results. The results of these tests compare favorably with those of the previous bomb-drop and rocket flights in that the velocities of the bombs at times of wing flutter are greater than the reference wing-flutter velocities. However, for the 45° sweptback wings, the components of these axial flutter velocities perpendicular to the leading edges of the wings are less than the reference wing-flutter velocities.

Use of separate telemeter channels for "breakwires" would give more definite indication of wing failure. However, the strain telemeter was found to be a satisfactory means of transmitting flutter data, indicating that the freely-falling-body technique with strain telemeters is an effective method of obtaining flutter data in the transonic range.

INTRODUCTION

The investigation of flutter characteristics in the transonic range is of immediate importance in aircraft design. It is desirable to use free-flight techniques such as freely falling bodies and rocket vehicles in addition to wind-tunnel testing to determine these flutter characteristics of airfoils near a Mach number of unity.

The freely-falling-body method is described in reference 1. This report is a continuation of that test program. These freely falling bodies,

[redacted]

henceforth to be called flutter bombs, were dropped from two altitudes other than that reported in reference 1, thus obtaining sonic velocities at different pressures. Six wings, four unswept with an aspect ratio of 2.75 and two swept 45° with an aspect ratio of 1.75, were attached to these bodies. These airfoils were NACA 65-009 sections in the plane perpendicular to the leading edge with a critical Mach number of 0.79 and were constructed of balsa wood with a duralumin insert.

The purpose of this report is to give the results obtained from three flutter bombs designated as FB-2, FB-3, and FB-4.

SYMBOLS

c	wing chord measured perpendicular to leading edge, inches
l	length of wing measured along midchord line, inches
E.A.	distance of elastic axis behind leading edge taken perpendicular to leading edge, percent chord
C.G.	distance of center of gravity behind leading edge taken perpendicular to leading edge, percent chord
M	Mach number
M_{cr}	theoretical Mach number at which sonic velocity is first attained over section of wing taken perpendicular to leading edge at zero lift
Λ	angle of sweep, positive for sweepback
φ	phase angle, wing torsional strain leading wing bending strain, degrees
A_g	aspect ratio of one wing panel $\left(\frac{(l \cos \Lambda)^2}{lc}\right)$
b	half chord of test wing measured perpendicular to leading edge, feet $\left(\frac{c}{2 \times 12}\right)$
a	nondimensional elastic-axis position $\left(\frac{2 \times \text{E.A.}}{100}\right) - 1$ (reference 2)

$a + x_\alpha$ — nondimensional center-of-gravity position $\left(\frac{2 \times \text{C.G.}}{100}\right) - 1$ (reference 2)

κ — ratio of mass of cylinder of testing medium of diameter equal to chord of wing to mass of wing, both taken for equal length of span $\left(\frac{\pi \rho b^2}{m}\right)$, where m is mass of wing per unit length

${r_\alpha}^2$ — square of nondimensional radius of gyration about elastic axis $\left(\frac{I_\alpha}{mb^2}\right)$, where I_α is polar moment of inertia about elastic axis (reference 2)

f_{h_1} — first bending natural frequency, cycles per second

f_{h_2} — second bending natural frequency, cycles per second

f_t — first torsion natural frequency, cycles per second

f_α — uncoupled first torsion frequency relative to the elastic axis, cycles per second $\left(f_t\left\{1 - \frac{{x_\alpha}^2}{{r_\alpha}^2\left[1 - \left(\frac{f_{h_1}}{f_t}\right)^2\right]}\right\}^{1/2}\right)$

f_{f_e} — experimental wing-flutter frequency, cycles per second

f_{f_o} — reference wing-flutter frequency, cycles per second (analysis similar to that used in determining V_{f_o})

$\omega_\alpha = 2\pi f_\alpha$, radians per second

t — time after release of missile from airplane, seconds

h — geometric altitude, feet

p_s — static pressure, pounds per square foot

T — free-air temperature, °F absolute

ρ — air density, pound × second^2 × feet^{-4}

q — dynamic pressure, pounds per square foot

v — velocity, feet per second

V — velocity, miles per hour

V_{f_e} — velocity of body at time of wing flutter, miles per hour

V_g — velocity of body at time of impact with ground, miles per hour

V_{f_o} reference wing-flutter velocity taken perpendicular to leading edge, miles per hour (based on theory for two-dimensional unswept wing in incompressible medium employing first bending frequency and uncoupled torsion frequency and density at time of flutter or impact with ground (reference 2))

V_{D_o} reference wing-divergence speed, miles per hour (based on theory for two-dimensional unswept wing in incompressible medium employing uncoupled torsion frequency and density of testing medium at time of flutter or impact with ground (reference 2))

$\frac{V}{b\omega_\alpha}$ nondimensional reference flutter velocity coefficient (reference 2)

APPARATUS AND METHODS

Model

A photograph and dimensional drawing of the complete model FB-2 are shown in figures 1 and 2. Similar photographs and drawings of the FB-3 and FB-4 are shown in figures 2, 3, 4, and 5. These 1300-pound flutter bombs were designed for high stability to reduce the effect of flutter or failure of one wing on the remaining wing. The airfoil parameters are listed in table I. Their geometric properties are shown in figures 6, 7, and 8.

Instrumentation

Each of the six wings was equipped with strain gages and a breakwire. The gages were mounted near the root of each airfoil to record both bending and torsional stresses on the wings numbered 1 and torsional stresses on wings numbered 2. The breakwires were run from the root out one surface of the wing, through the wing near the tip, and back down the other surface to the root. They were wired into the circuit of the torsion strain-gage channel so that the breaking of the wire turned off the transmitter of that channel and resulted in noise or hash instead of a definite signal on the oscillograph record A longitudinal accelerometer was mounted in each bomb at approximately the center-of-gravity position. Signals from the strain gages and accelerometers were transmitted over four telemeter channels simultaneously to two receiving stations. This strain telemeter was recently developed by the Langley Instrument Research Division of the National Advisory Committee for Aeronautics. The data from the telemeters were recorded by a recording oscillograph at each receiving station. The time of release, as indicated by a switch activated by the bomb leaving the plane, was also recorded on these oscillographs. Radar and phototheodolite were used to assist in determining the altitude and speed of the airplane at time of drop.

Measurements

In addition to strain telemeter data, measurements similar to those reported in reference 1 were taken of ground parameters and atmospheric and flight conditions.

Reduction of Data

The reduction of principal data is similar to that in reference 1. Flutter was indicated when the signal from the strain gages showed a definite oscillation which increased rapidly in amplitude. On those records which had signals from both bending and torsion gages the oscillations were of the same frequency. Associated conditions were determined from the time-history curves. The phasing of the bending and twisting of the wings was determined from the telemetered strain records using the deflection sign convention of reference 2 and arbitrarily recorded in this report as torsion strains leading bending strains.

RESULTS AND DISCUSSION

The time histories of the falls of the three flutter bombs are shown in figures 9, 10, and 11. Here the variation of the bomb altitude, velocity, and Mach number are plotted together with free-air static pressure and temperature that correspond to geometric altitude of the bomb.

Final results are listed in table II. Figures 12, 13, and 14 are reproductions of the original oscillograph records taken during the falls of the flutter bombs.

Figure 12 is the flutter record of the FB-2. This is apparently bending-torsion flutter. There is noted from the bending and torsion strain-gage channels of the first wing, designated 2001, the flutter frequency of 29.1 cycles per second. The amplitude of this flutter built up very rapidly with the wing torsion leading bending by 137.5°. A sharp jump in the trace of the accelerometer channel and the failure of the strain-gage channels are also indications of flutter. Unfortunately, the torsion channel of wing 2002 was inoperative, and it was impossible to determine whether the wing fluttered. This bomb reached a top Mach number of 1.01.

Figure 13 is the flutter record of the FB-3. There is noted from the trace of the bending-gage channel of the first wing (3001) the flutter frequency of 20.5 cycles per second. Because of the large amount of "hash" in the torsion channel, it was difficult to read the torsion frequency; but, by drawing a mean line, the flutter frequency was again found to be 20.5 cycles per second. The amplitude of both bending and torsion built up very rapidly with torsion leading bending by 28°. The record of the stiffer wing, 3002, indicated that this wing did not flutter or fail in the descent of the bomb. The maximum Mach number attained was 1.145.

Figure 14 is the flutter record of the FB-4. The wings on this bomb had 45° sweepback and fluttered in symmetrical mode. There is noted from the traces of the torsion and bending strain-gage channels of the first wing (4001) the flutter frequency of 26.7 cycles per second. The amplitude built up rapidly and showed the torsion leading bending by 151°. For wing 4002, there is noted a rapid build-up in amplitude at a frequency of 26 cycles per second, and a continued large amplitude oscillation with the frequency decreasing to 23.1 cycles per second when the channel became inoperative. This bomb continued to a Mach number of 1.20.

There is insufficient evidence to state positively that the wings failed to complete destruction after fluttering. Use of separate telemeter channels for the breakwires would give more definite indication of wing failure. Although it was difficult to ascertain the actual wing bending-torsion amplitude because of the unknown flutter-deflection mode, it appears that the stresses in these fluttering wings were sufficient to cause failure.

In order to have a basis for comparing these tests with the experimental techniques of references 1, 3, and 4, flutter calculations were made using the two-dimensional, incompressible flutter theory for unswept wings of reference 2. In figure 15 the variation in the calculated flutter-velocity coefficients with frequency ratios for the six wings are shown. This figure was plotted from the calculations using the densities at the altitudes of flutter for the four wings which fluttered, and at impact for the other two. Also shown in figure 15 are the bending-frequency spectra. These ratios of first and second bending frequencies to the torsion frequency are indicated above the abscissa scale. The values of V_{f_o} for the six wings were determined, using the first bending-torsion frequency ratios. Comparing the experimental values with the reference values (table II), it is seen that the experimental values of flutter speed exceed the reference values by 9 percent at $M = 0.84$ and 19 percent at $M = 0.895$ for the two unswept wings. These percentages compare favorably with those reported in references 1 and 4.

The velocity of the FB-4 at the time of flutter of the 4001 and the 4002 wings exceeded the theoretical flutter speeds by 21 percent at $M = 0.92$ and 15 percent at $M = 0.925$, respectively. A rocket-borne 45° sweptback wing (reference 3), the failure of which was indicated by the opening of a breakwire, failed at a missile velocity 76 percent greater than the reference flutter speed. The Mach number of the missile at the time of failure was 0.89.

If it is desired to compare the component of the body velocity perpendicular to the leading edge of the wing with the reference flutter speed, which is also perpendicular to the leading edge of the wing, it is seen that the percentage difference is reduced from 76 percent to 24 percent for the rocket wing of reference 3. Similar analysis of the flutter velocities of the 4001 and the 4002 wings shows that the component of flutter velocity perpendicular to the leading edge ($V_{f_e} \cos \Lambda$) is less than the reference flutter speed by 14 percent and 19 percent, respectively.

CONCLUDING REMARKS

Data have been presented showing that four airfoils fluttered at transonic Mach numbers; two unswept wings at 0.84 and 0.895, and two wings with 45° sweepback at M = 0.92 and 0.925. The flutter frequencies were 29.1, 20.5, 26.7, and 26.0 cycles per second, respectively. In the first three cases where phasing was recorded, torsion led bending by 137.5°, 28°, and 151°.

One unswept airfoil reached the top Mach number of the bomb, M = 1.145, without failure or flutter. The telemeter channel of the sixth airfoil, which was unswept, was inoperative and no conclusive data were obtained.

Two-dimensional, incompressible flutter theory for unswept wings was used to calculate reference flutter velocities of these wings for preliminary comparison with other experimental results. The results of these tests compare favorably with those of the previous bomb-drop and rocket flights in that the velocities of the bombs at times of wing flutter are greater than the reference flutter velocities. However, for the 45° sweptback wings, the components of these axial flutter velocities perpendicular to the leading edge of the wing are less than the reference flutter velocities.

Use of separate telemeter channel for breakwires would give more definite indication of wing failure. However, the strain telemeter was found to be a satisfactory means of transmitting flutter data, indicating that the freely-falling-body technique with strain telemeters is an effective method of obtaining flutter data in the transonic range.

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REFERENCES

1. Barmby, J. G., and Clevenson, S. A.: Initial Test in the Transonic Range of Four Flutter Airfoils Attached to a Freely Falling Body. NACA RM No. L7B27, 1947.

2. Theodorsen, Theodore, and Garrick, I. E.: Mechanism of Flutter - A Theoretical and Experimental Investigation of the Flutter Problem. NACA Rep. No. 685, 1940.

3. Angle, Ellwyn E.: Initial Flight Test of the NACA FR-1-A, a Low Acceleration Rocket-Propelled Vehicle for Transonic Flutter Research. NACA RM No. L7J08, 1947.

4. Barmby, J. G., and Teitelbaum, J. M.: Initial Flight Tests of the NACA FR-2, a High-Velocity Rocket-Propelled Vehicle for Transonic Flutter Research. NACA RM No. L7J20, 1948.

TABLE I

AIRFOIL PARAMETERS

Parameter	Airfoil number					
	2001	2002	3001	3002	4001	4002
Section	65009	65009	65009	65009	65009	65009
M_{cr}	0.79	0.79	0.79	0.79	0.79	0.79
c	8	8	8	$7\frac{7}{8}$	8	8
l	22	22	22	22	28	28
A_g	2.75	2.75	2.75	2.79	1.75	1.75
Λ	0	0	0	0	45	45
b	0.333	0.333	0.333	0.328	0.333	0.333
C.G.	44	45.3	44.9	46	46	45
E.A.	37	35	30	28.8	37	30
a	-0.26	-0.30	-0.40	-0.424	-0.26	-0.40
$a + x_\alpha$	-0.12	-0.094	-0.102	-0.08	-0.08	-0.10
$1/\kappa$ (stnd.)	55.3	69	50.5	70.2	57.8	63.9
r_α^2	0.184	0.171	0.256	0.256	0.205	0.231
f_{h_1}	15	13	12	14.7	8.6	9.06
f_{h_2}	93	84	72	93.2	51.3	53.6
f_t	100	127	83.5	123	75	84.1
f_α	94.5	109	67.1	89.5	70	66.1

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TABLE II

RESULTS OF DROPS

INFORMATION AT TIME OF WING FLUTTER

OR IMPACT WITH GROUND

Parameter	Airfoil number					
	2001	2002	3001	3002	4001	4002
Section	65009	65009	65009	65009	65009	65009
M	0.840	[a]1.01	0.895	[a]1.145	0.920	0.925
V_{f_e}	610	--------	634	--------	645	653
V_g	768	768	902	902	930	930
ρ	0.00170	0.00235	0.00110	0.00225	0.00110	0.00111
q	677	1482	476	1970	491	518
$1/\kappa$	77.3	70	111	74.2	125	137
t	24.70	36.00	25.70	48.4	26.38	26.68
h	10,656	0	24,598	0	24,450	24,100
T	477	519	452	546	448	452
p_s	1395	2086	830	2120	836	848
φ	137.5	--------	28	--------	151	--------
$V_{f_e} \cos \Lambda$	610	--------	634	--------	456	462
V_{f_o}	560	587	534	576	531	570
V_{D_o}	735	850	1140	1430	794	1185
f_{f_e}	29.1	--------	20.5	--------	26.7	26
f_{f_o}	43.2	52	40	60.5	31.1	37

[a]At impact.

[redacted]

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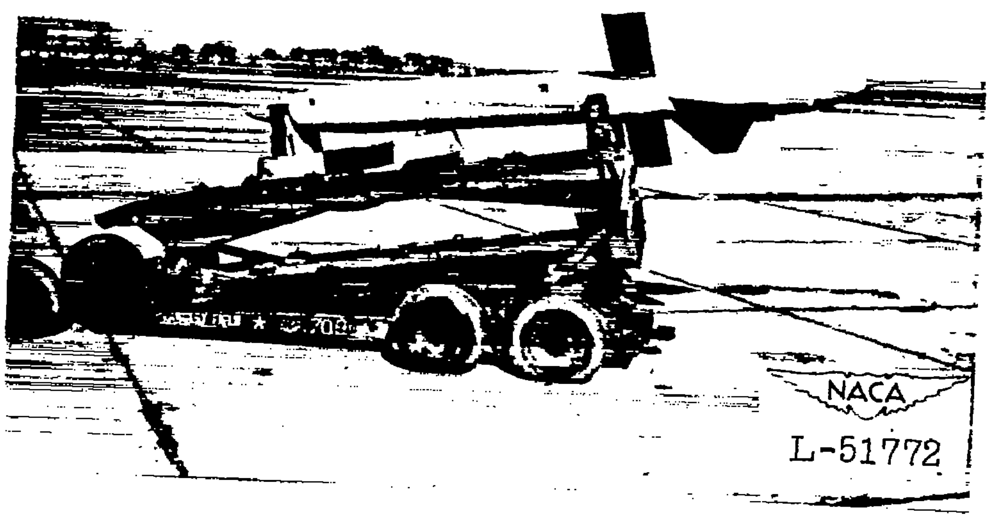

Figure 1.- Flutter bomb FB-2.

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[redacted]

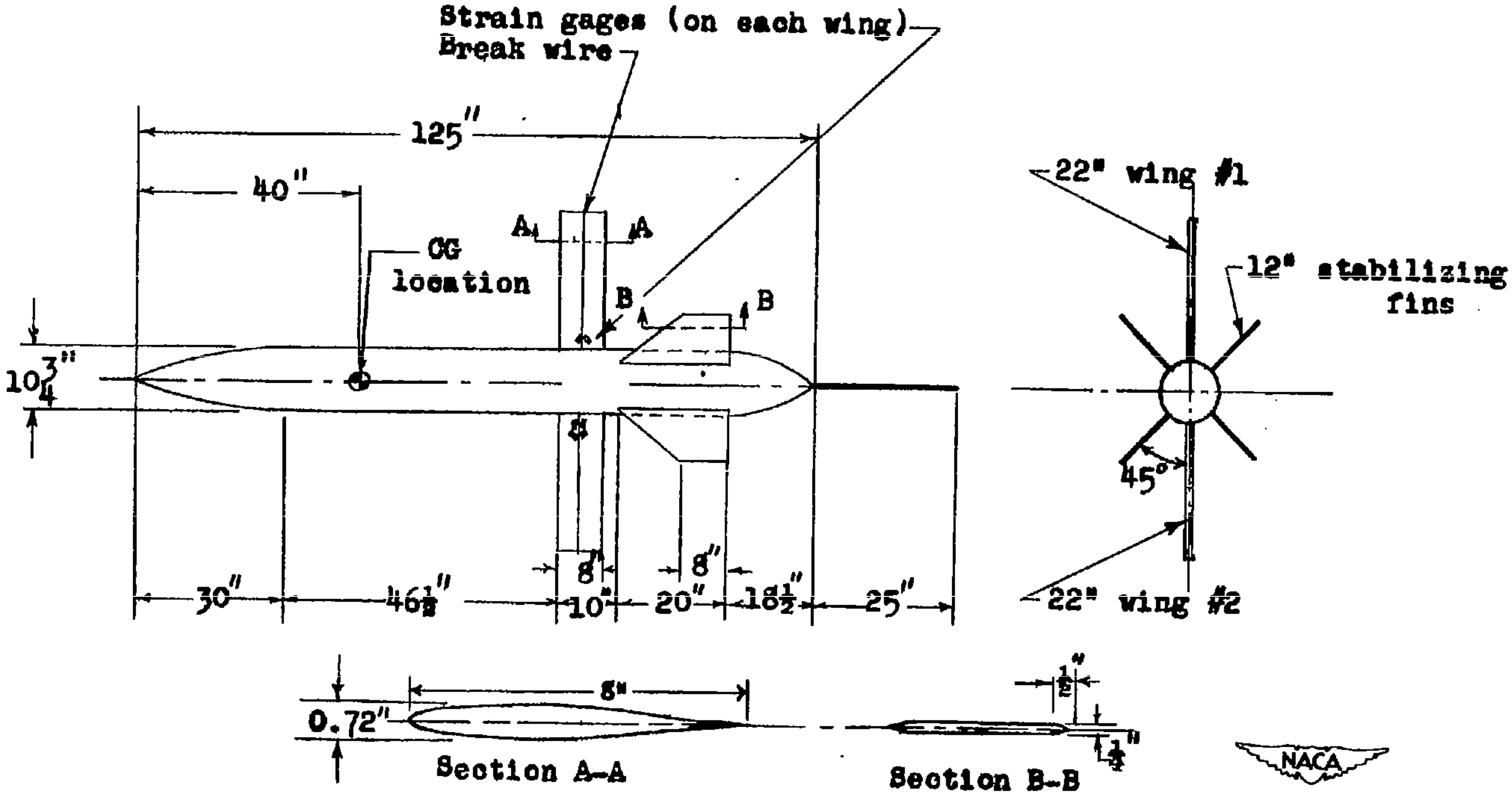

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Figure 2.-Dimensional drawing of the FB-2 and FB-3.

[redacted]

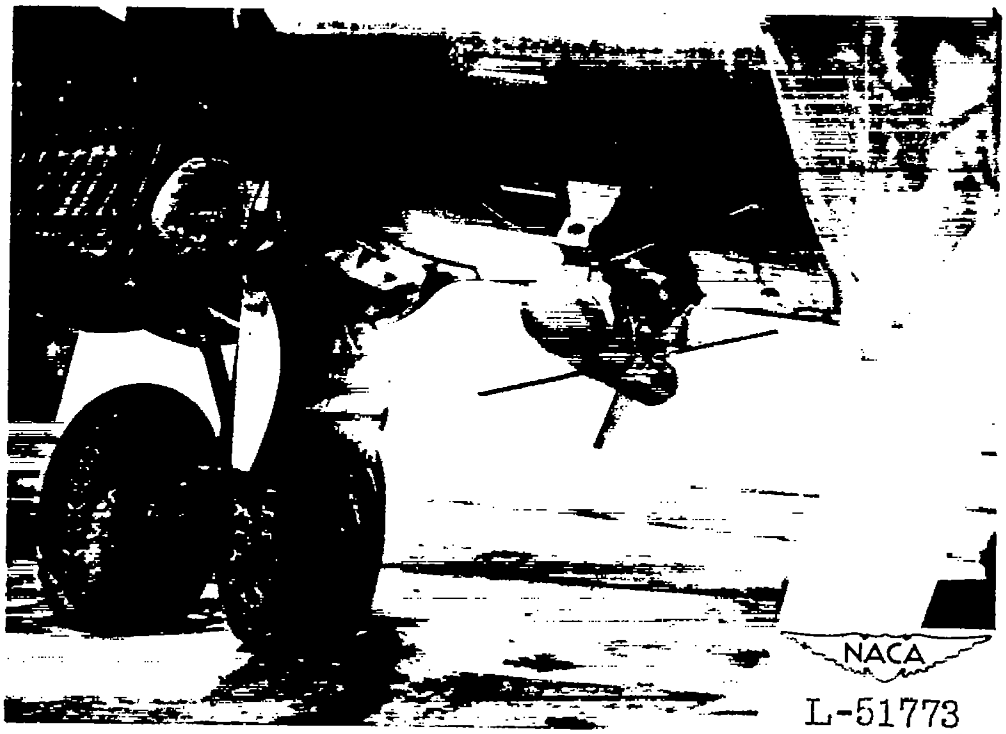

Figure 3.- Flutter bomb FB-3.

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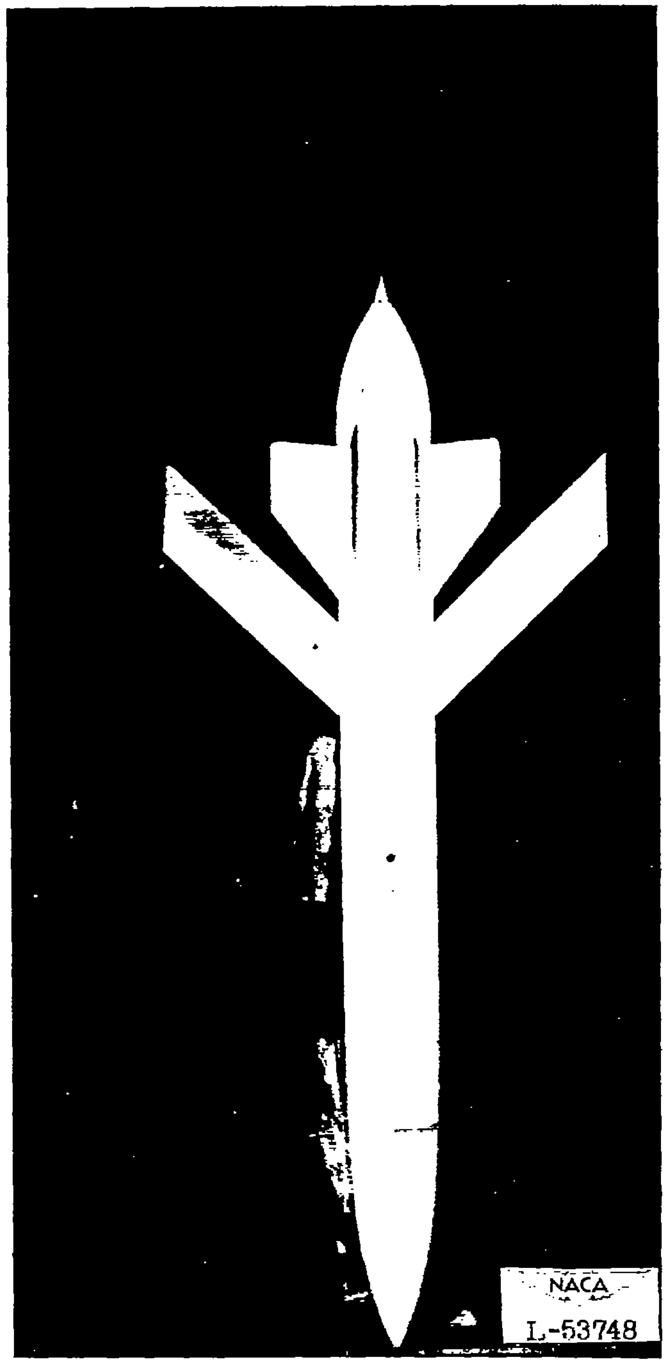

Figure 4.- Flutter bomb FB-4.

[redacted]

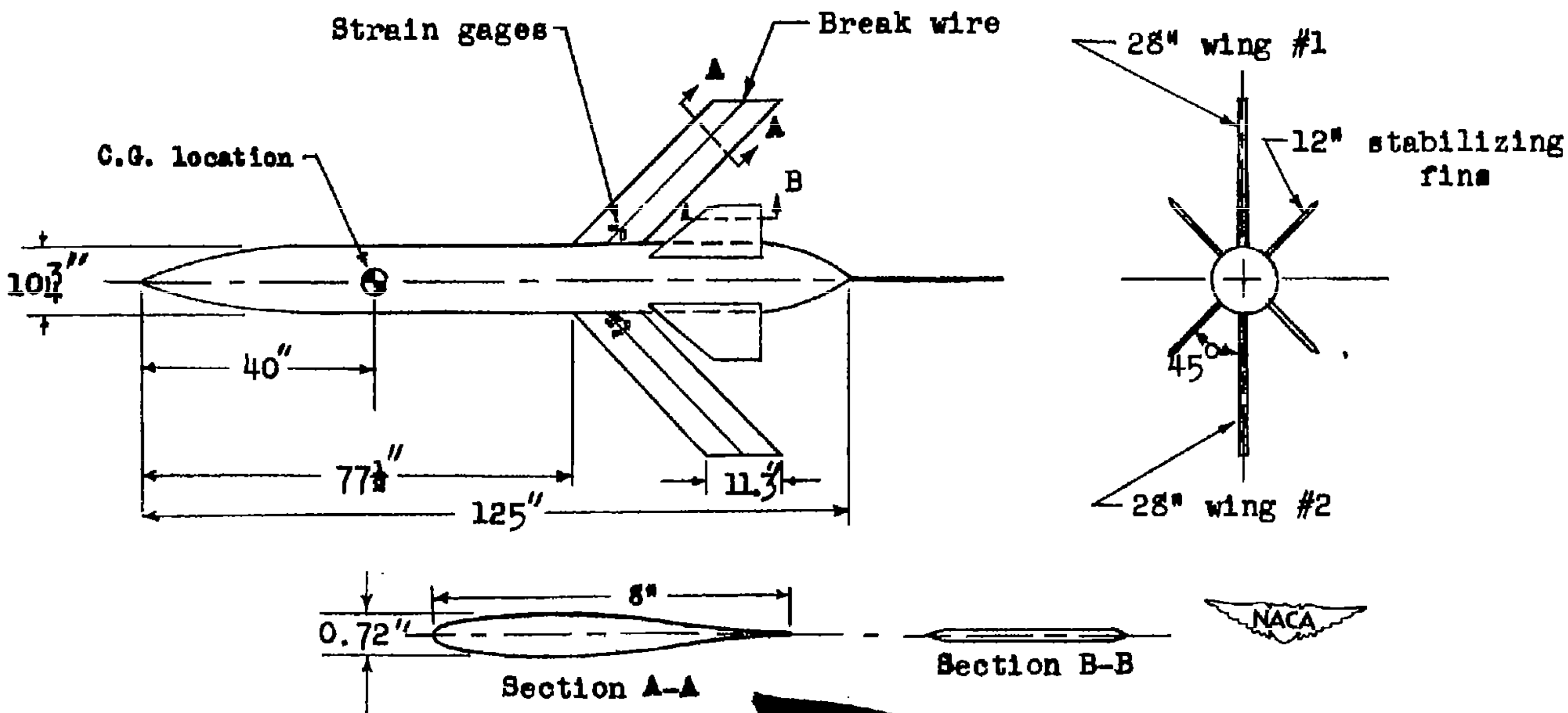

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Figure 5.-Dimensional drawing of the FB-4.

[redacted]

[redacted]

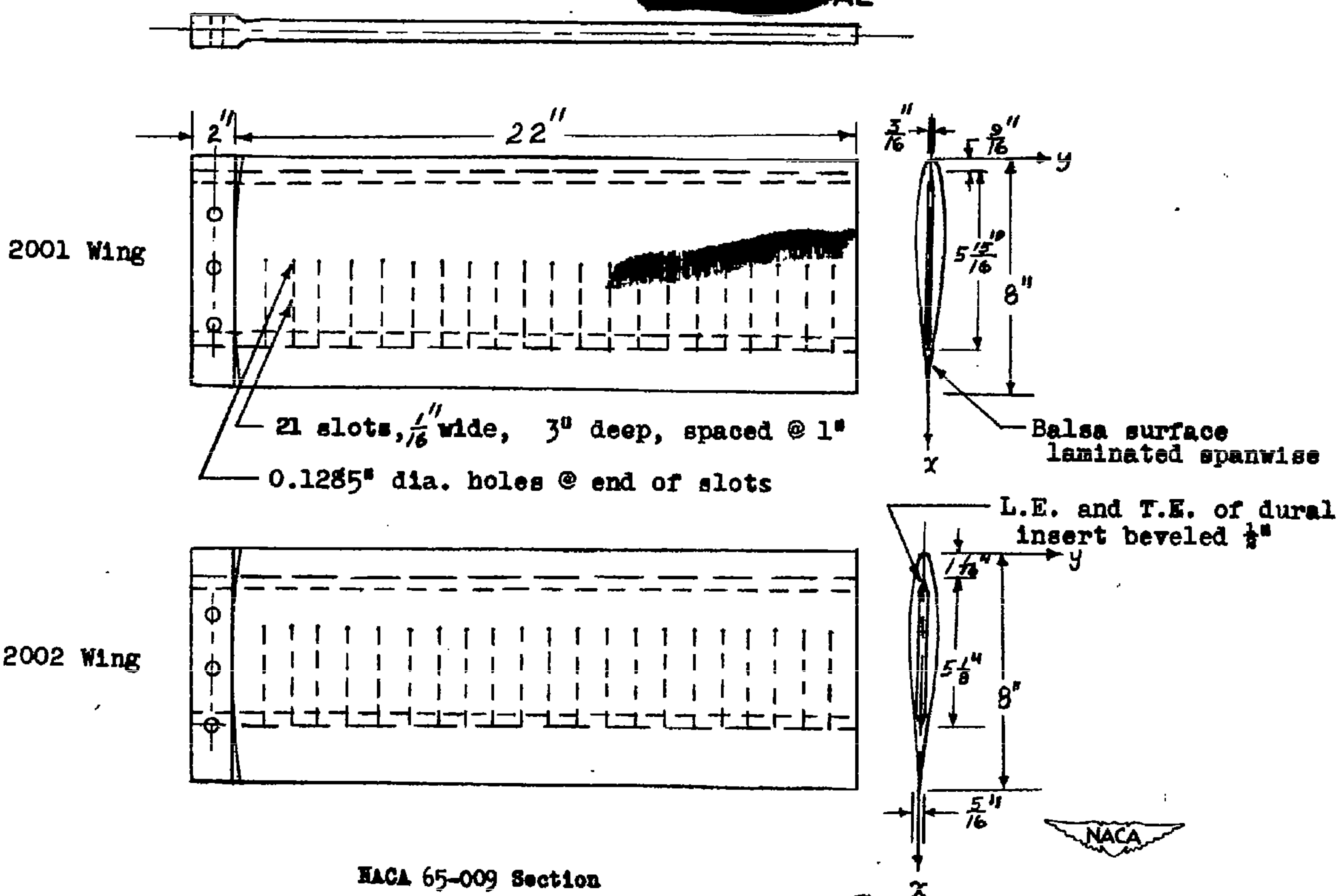

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Figure 6.-Geometric properties of the FB-2001 and 2002.

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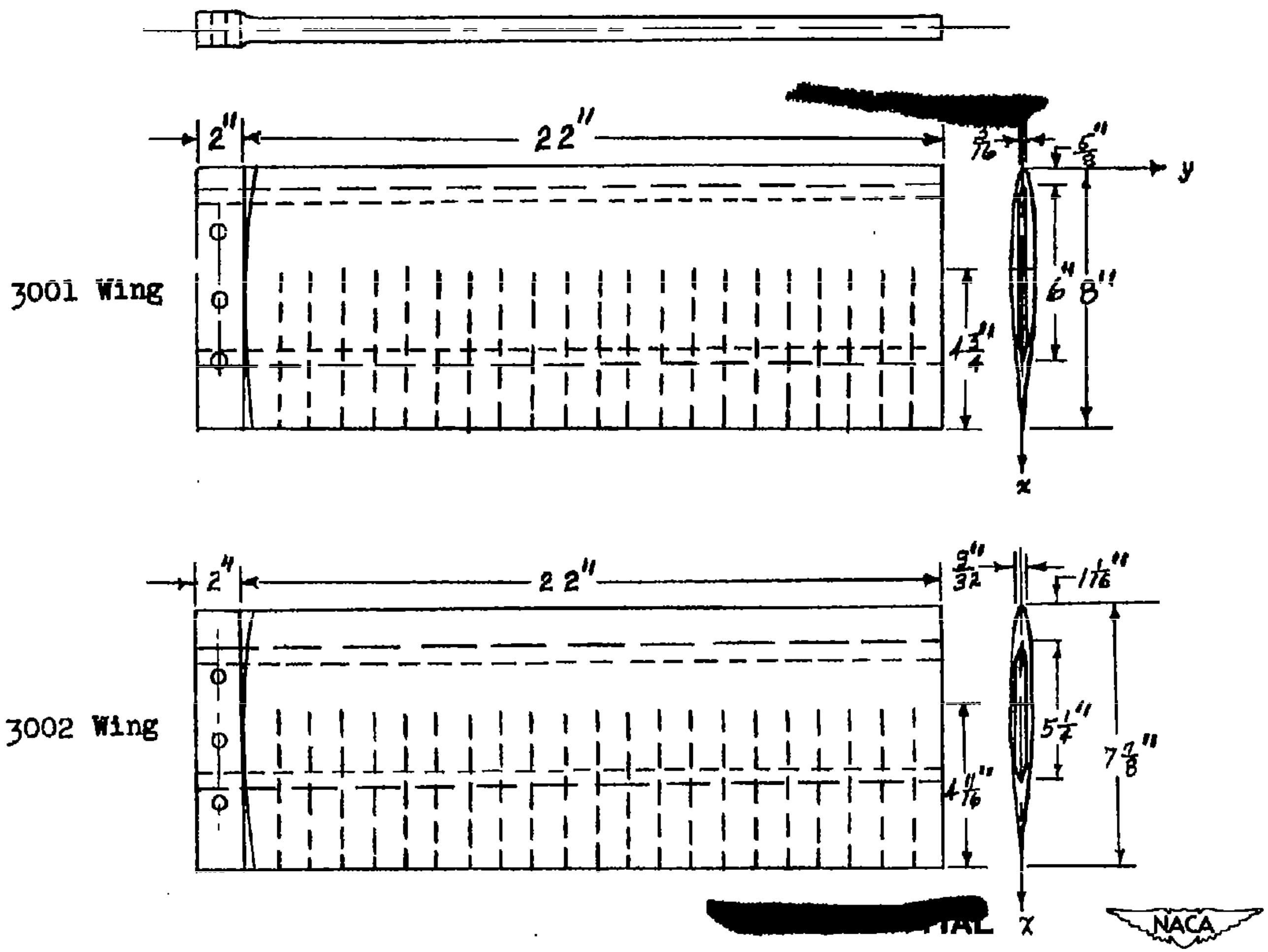

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NACA 65-009 Section

NACA 65-009 Section

x	$y_u = y_l$
0.00	0.000
0.10	0.085
0.20	0.114
0.40	0.157
0.60	0.191
0.80	0.219
1.20	0.264
1.60	0.298
2.40	0.342
3.20	0.360
4.00	0.346
4.80	0.300
5.60	0.228
6.40	0.144
7.20	0.059
7.60	0.022
8.00	0.00

[redacted]

Figure 7.-Geometric properties of the FB-3001 and 3002.

[redacted]

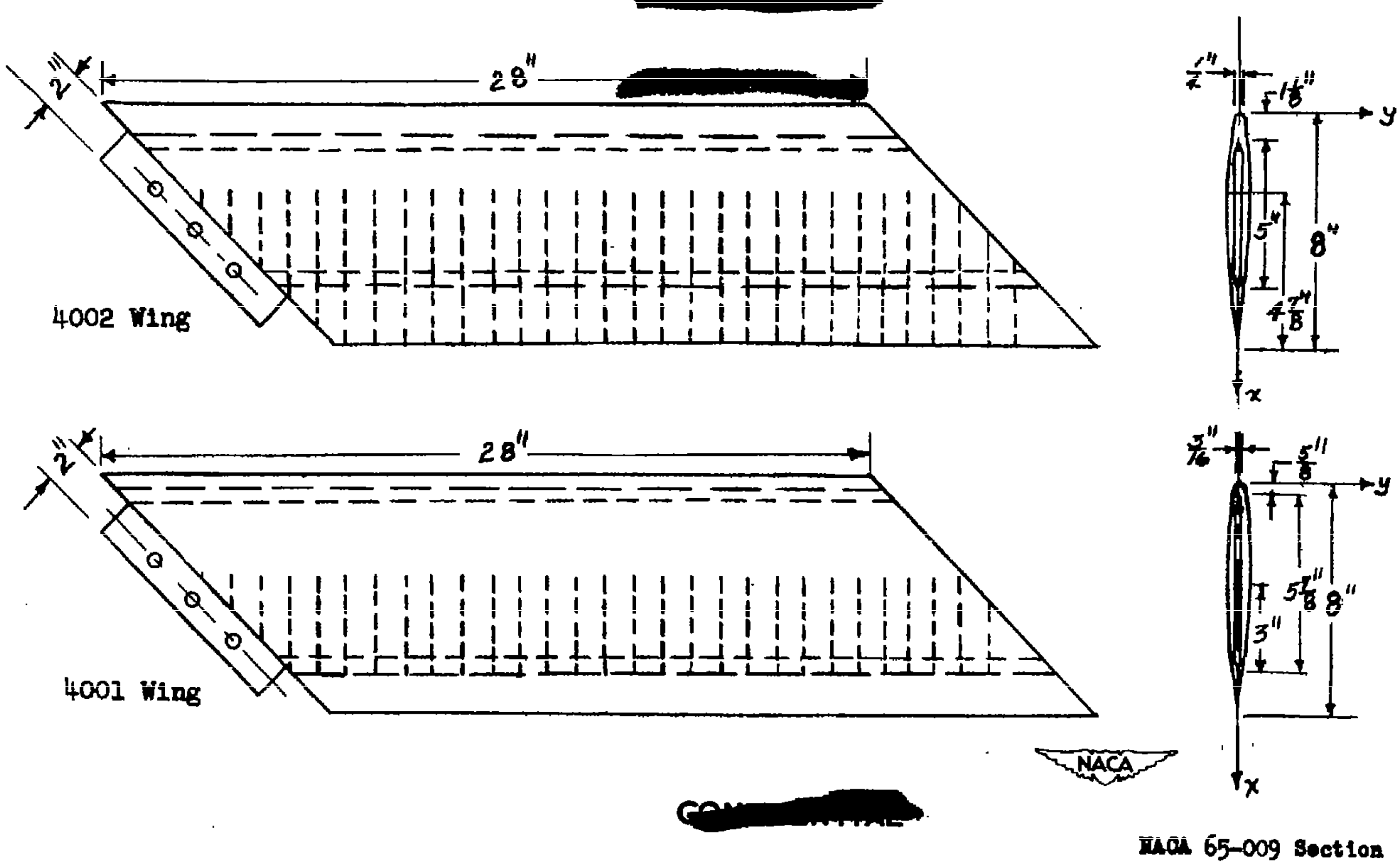

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Figure 8.-G[redacted]perties of the FB-4001 and 4002.

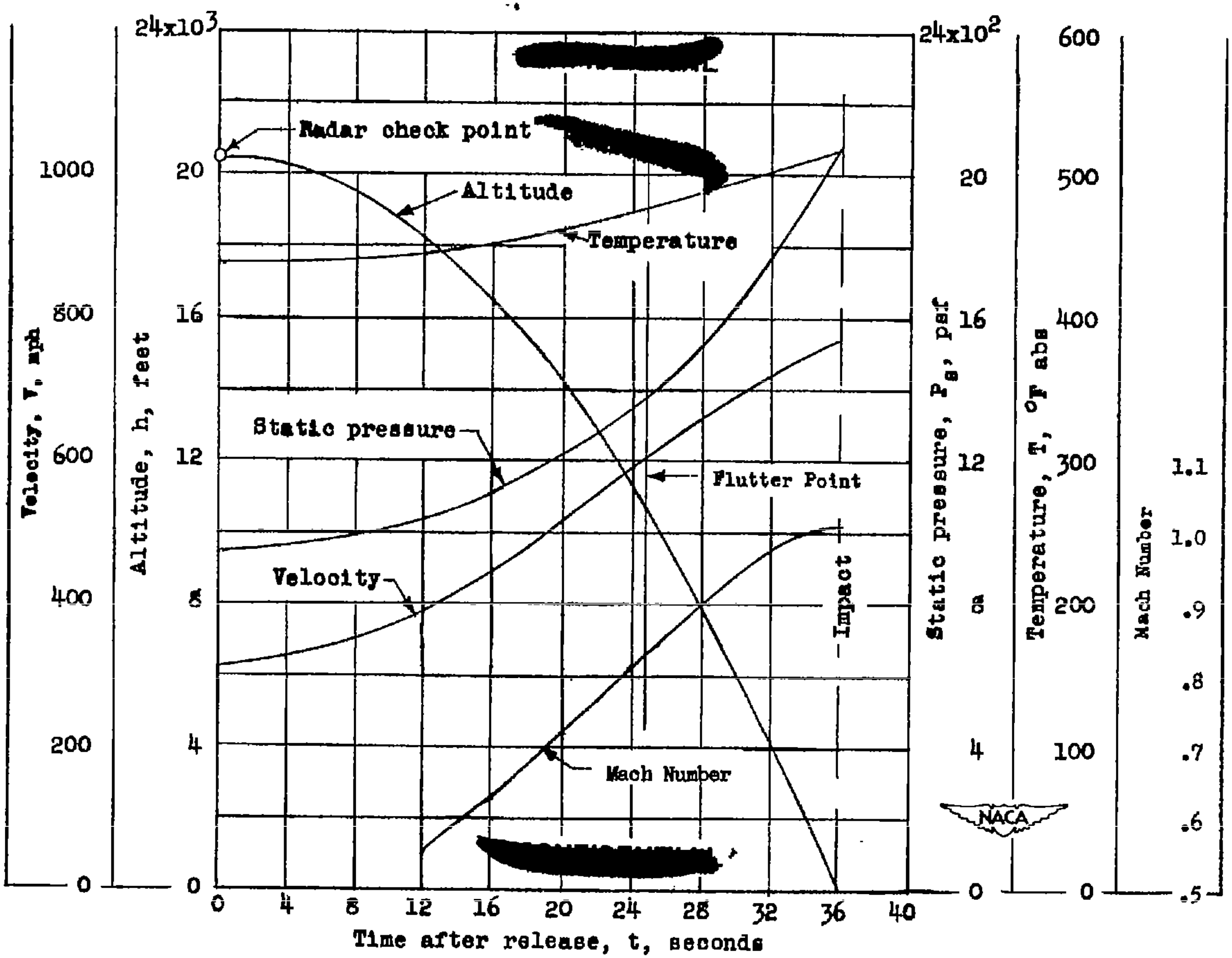

Figure 9.-Time history of fal[redacted].

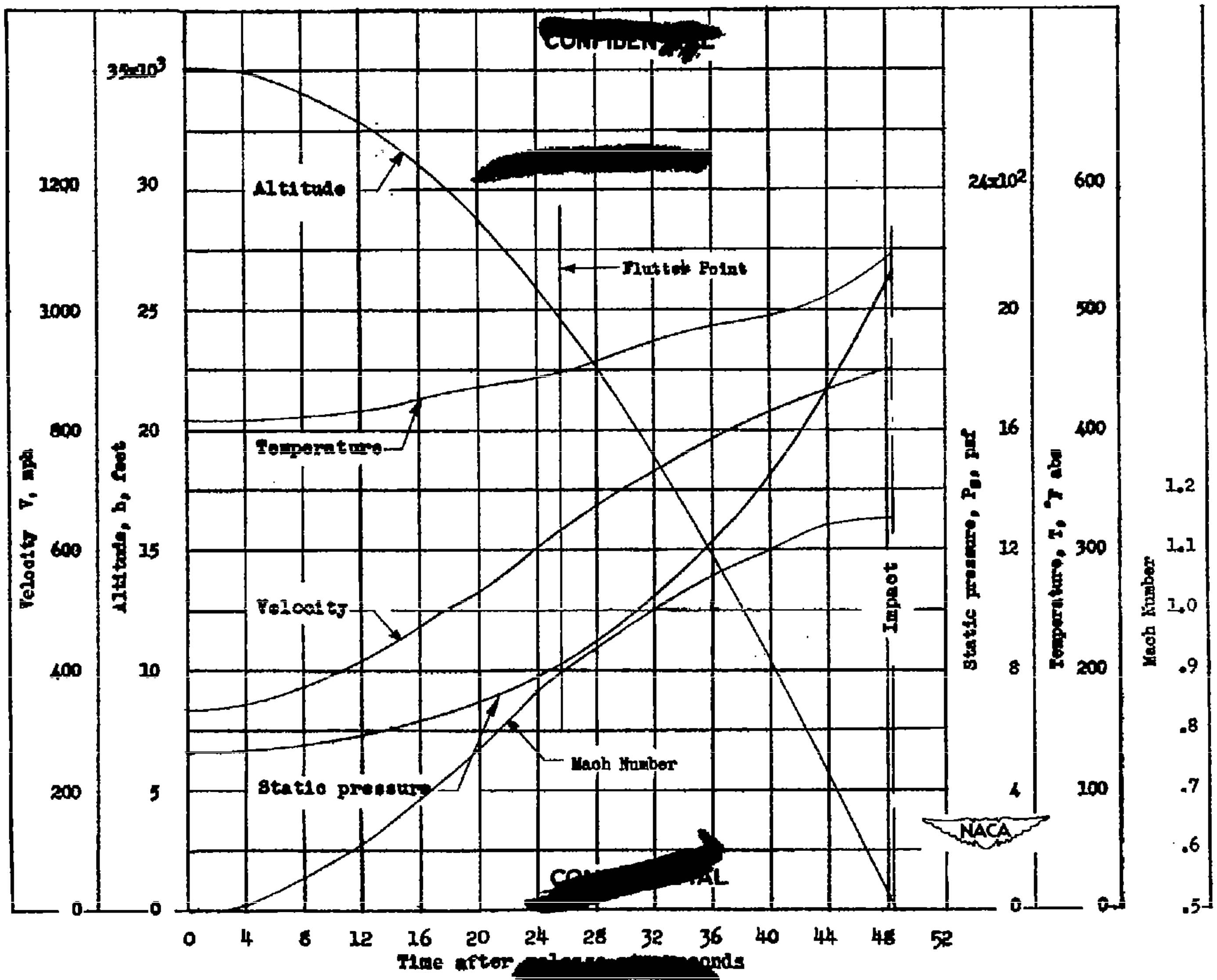

Figure 10.-Time history of fall of the FB-3.

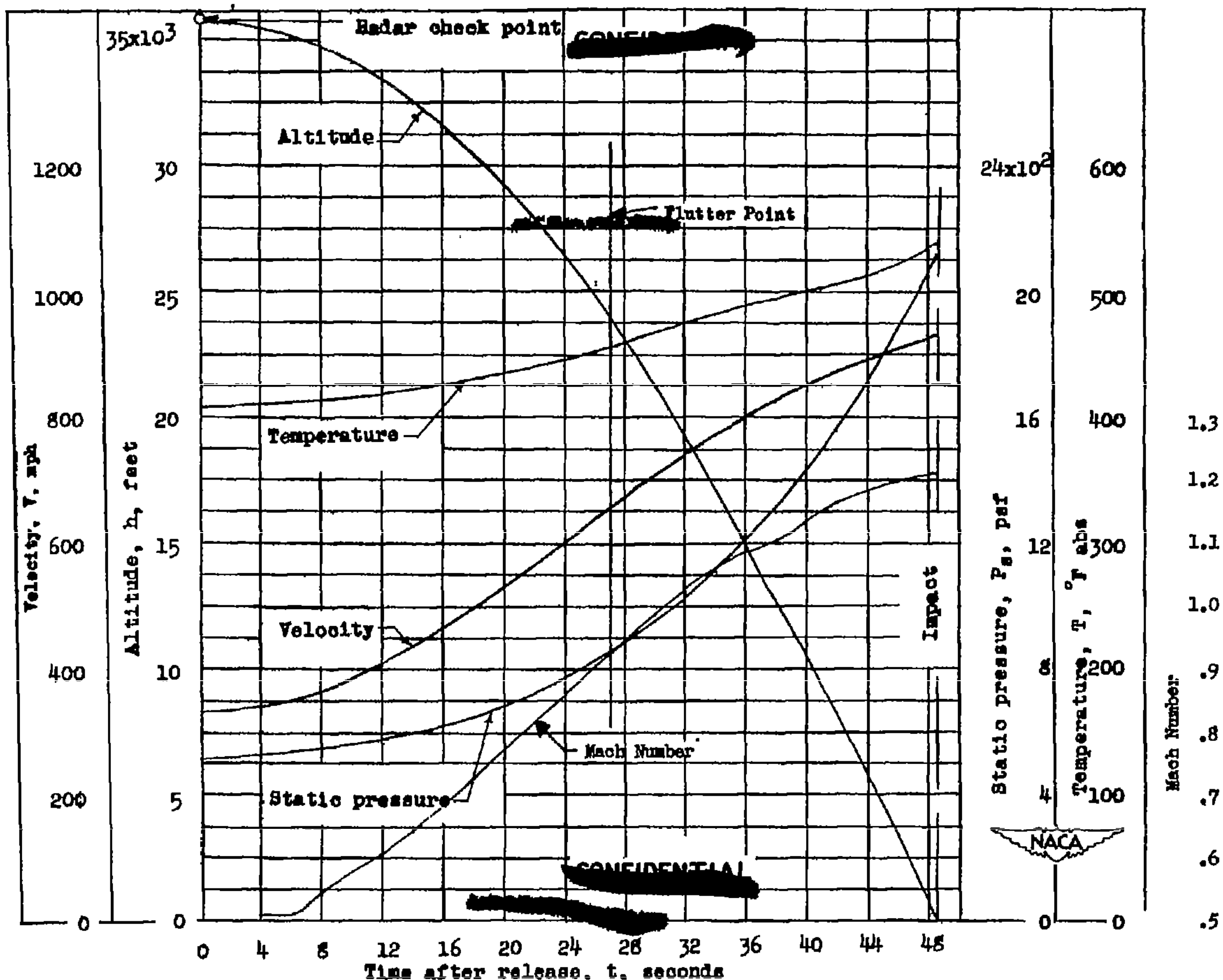

Figure 11.–Time history of fall of the FB-4.

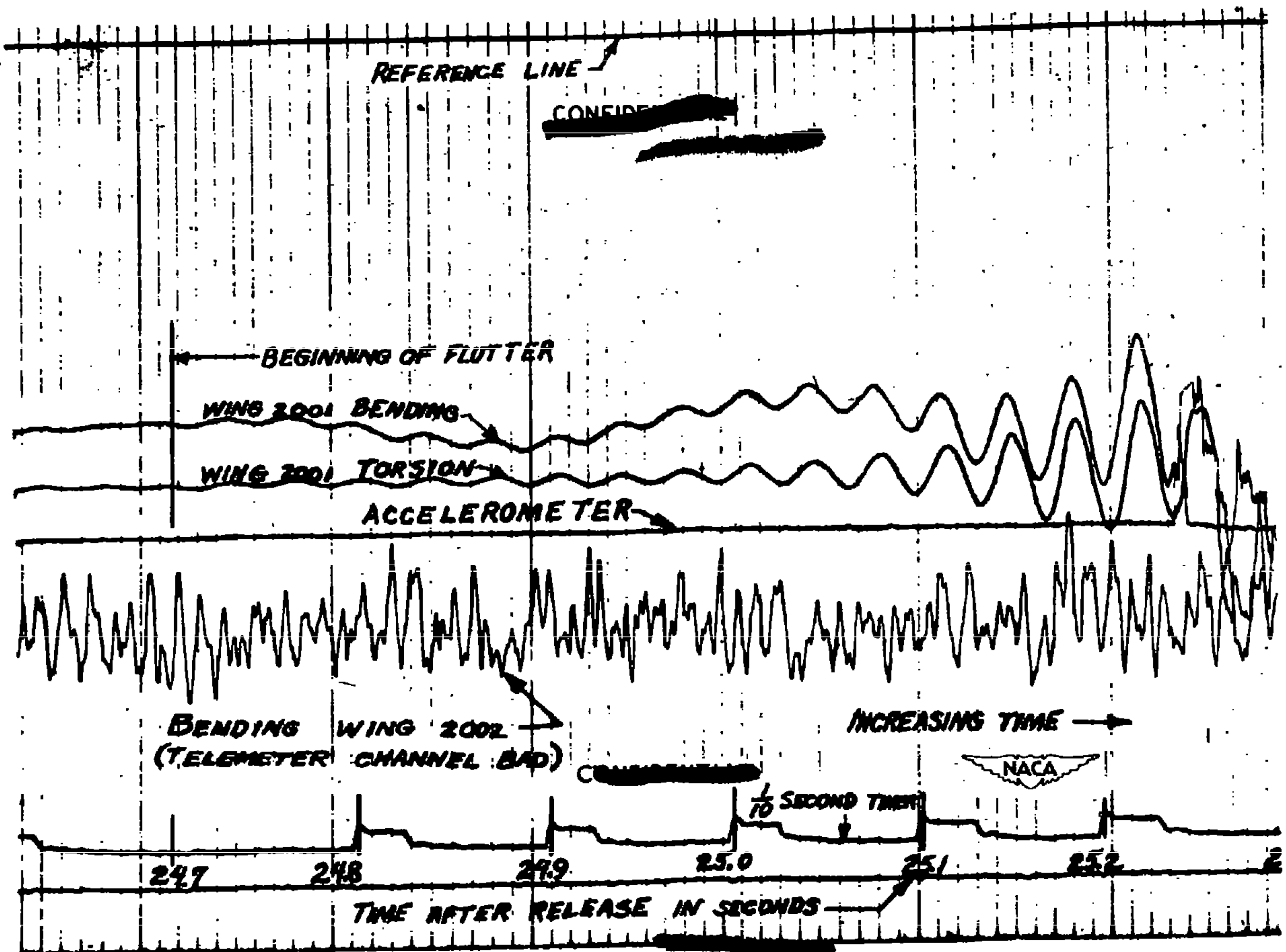

Figure 12.-Sample oscillograph record showing the flutter of wing number 1 on the FB-2.

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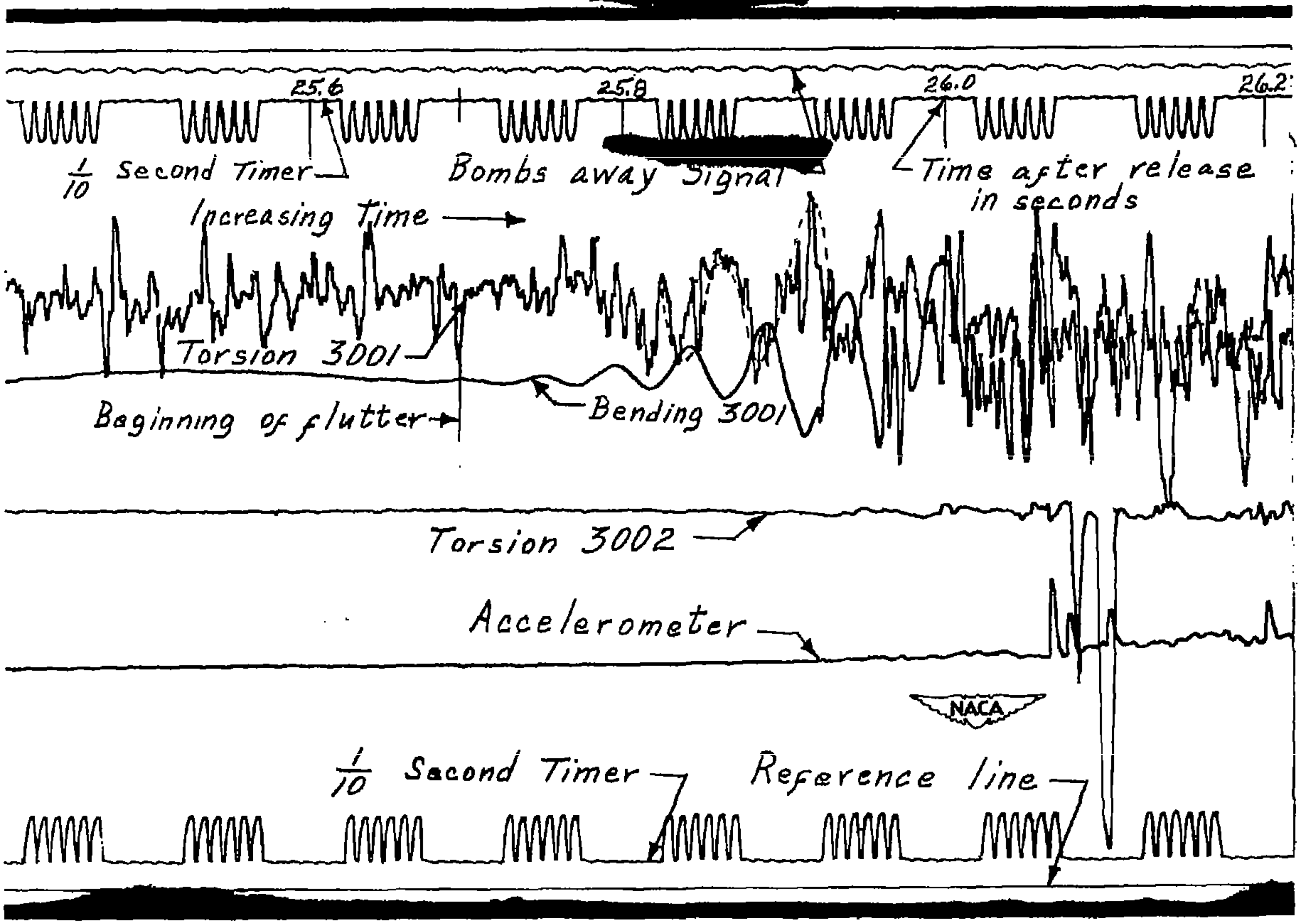

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Figure 13.-Sample oscillograph record showing the flutter of wing number 1 on the FB-3 [redacted]

[redacted]

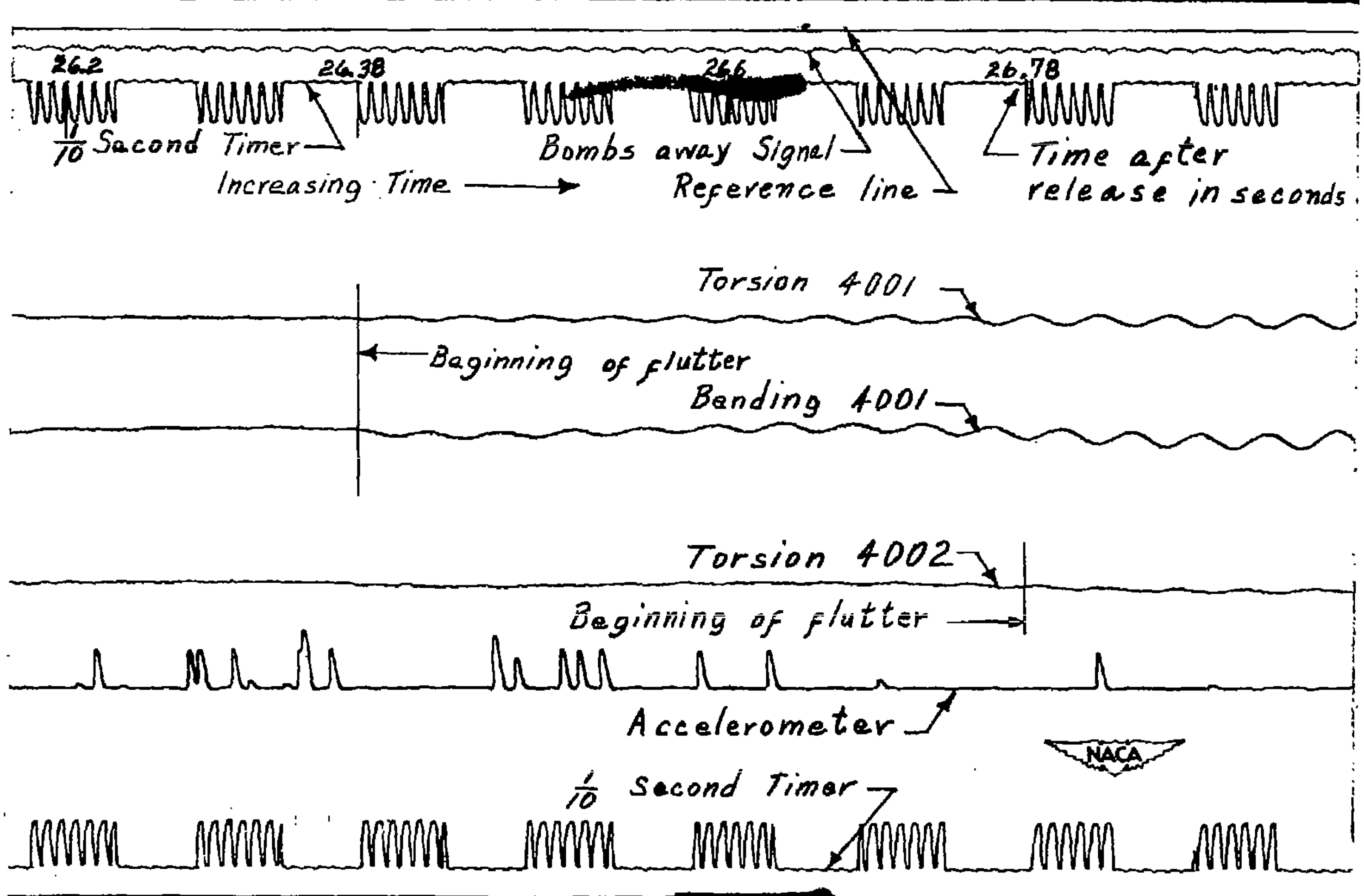

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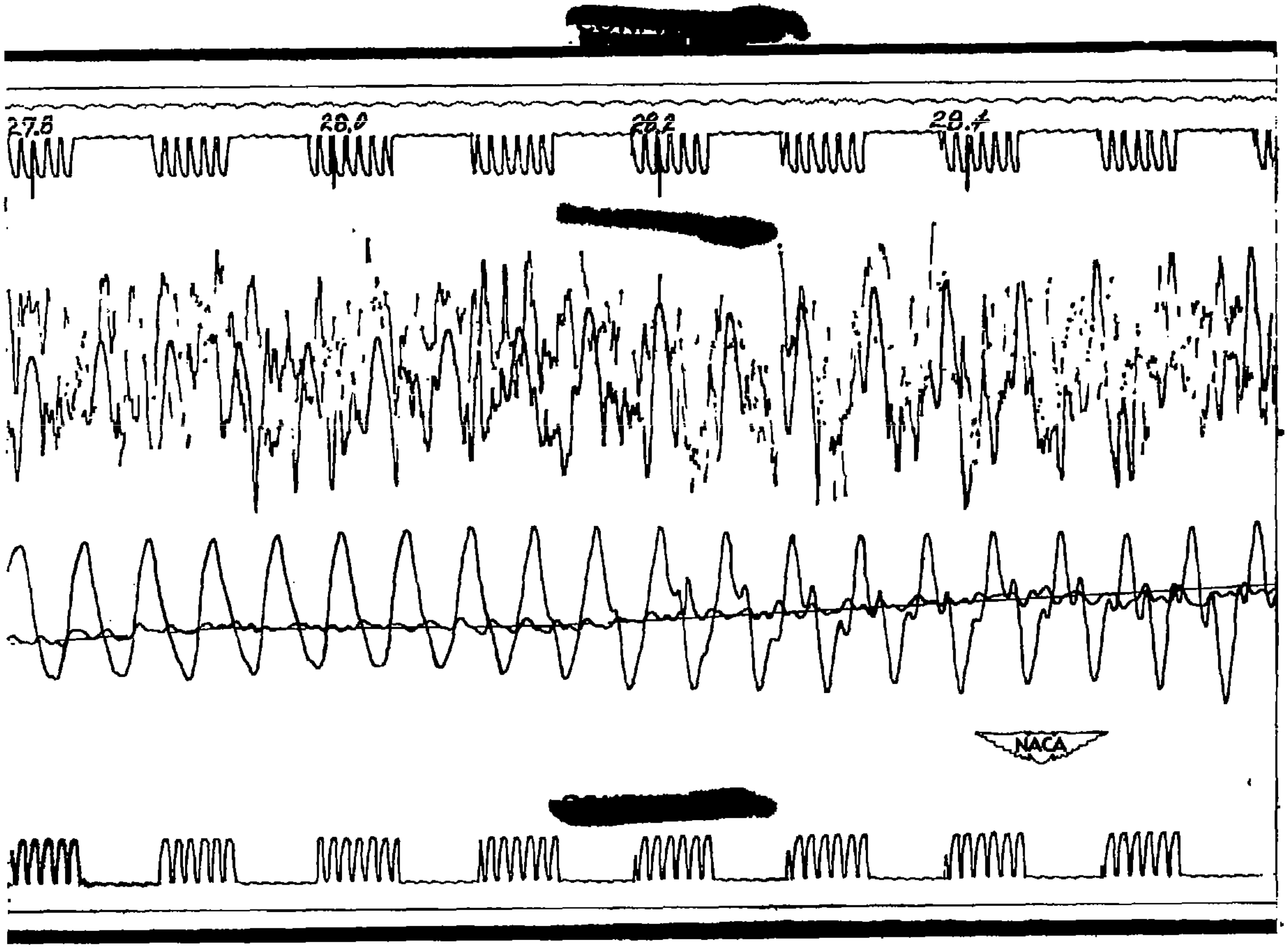
Figure 14.-Sample oscillograph record showing the flutter of wing number 1 and the large amplitude oscillation of wing number 2 on the [redacted]



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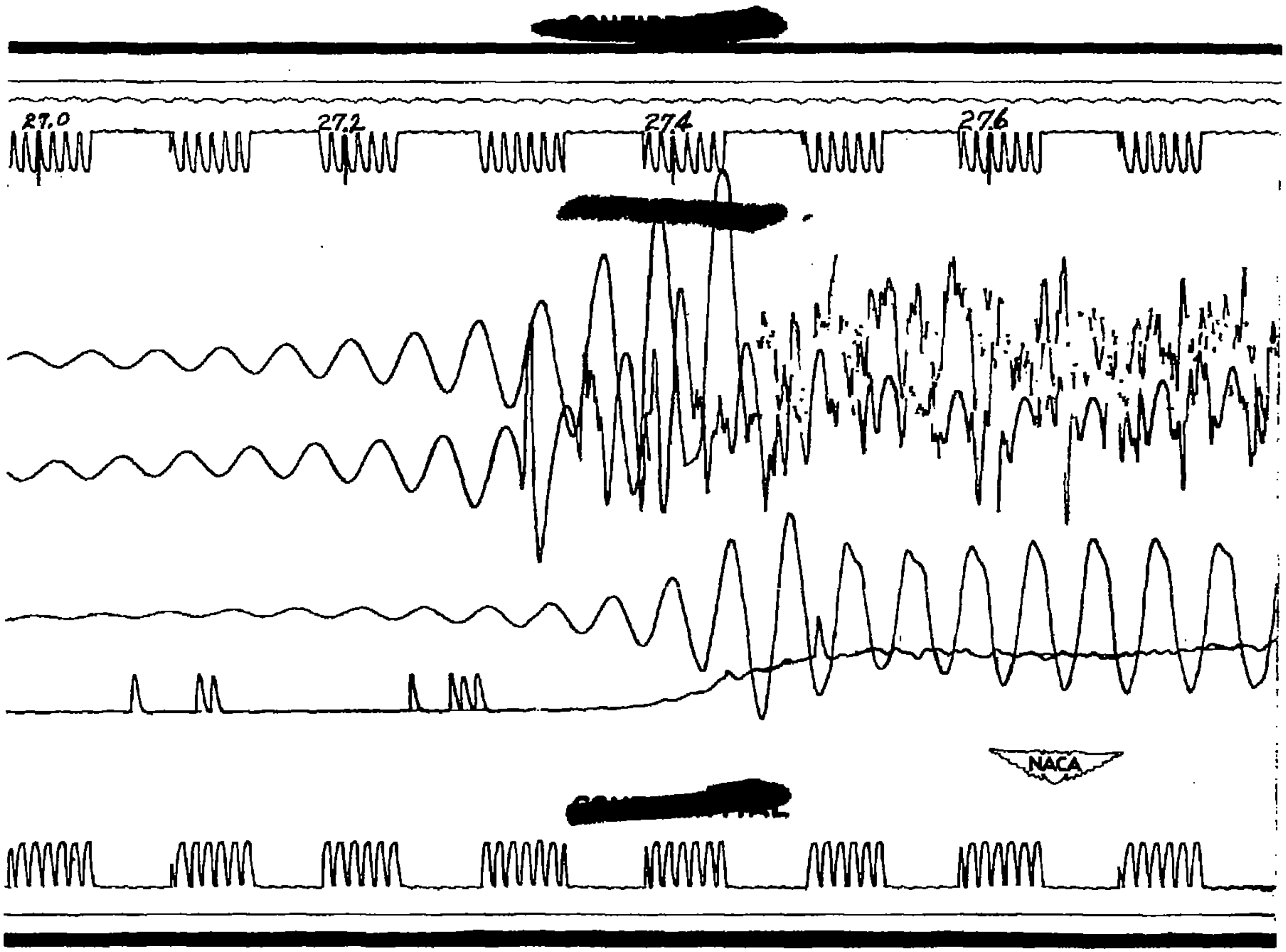

Figure 14. [redacted]

[redacted]

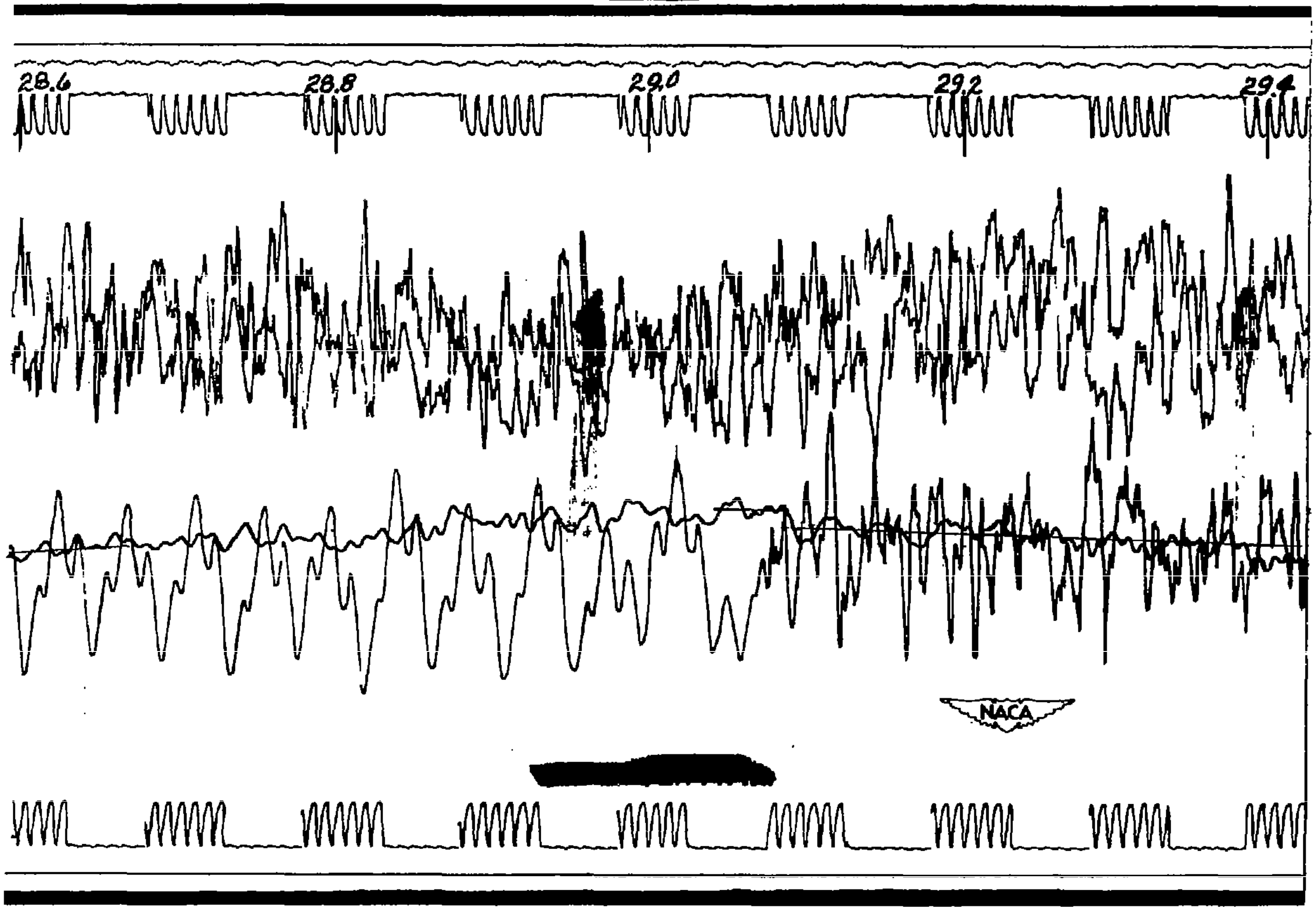

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Figure 14. - (concluded)

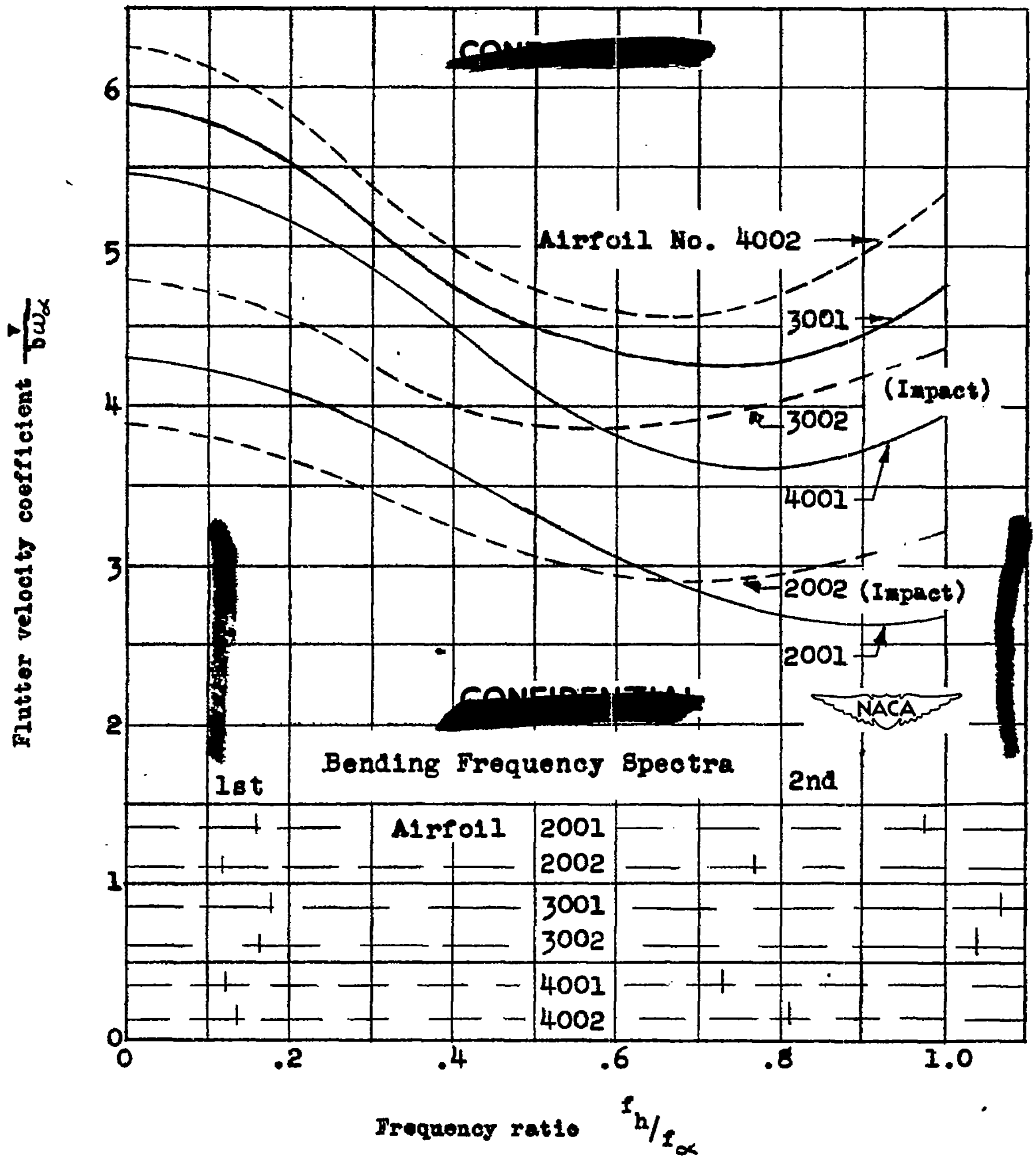

Figure 15.- Reference flutter velocity coefficient as a function of frequency ratio. Two-dimensional, incompressible theory for an unswept wing using air density at time of flutter or impact.